Economic Aspects of Gold Exploration: How Much Is Too Much?

Brian W. Mackenzie
Michael D. Doggett

Working Paper No. 44

Centre for Resource Studies

Economic Aspects of Gold Exploration:

How Much Is Too Much?

Brian W. Mackenzie

and

Michael D. Doggett

Centre for Resource Studies
Queen's University
Kingston, Ontario

November 1989

Canadian Cataloguing in Publication Data

Mackenzie, Brian W., 1939-
Economic aspects of gold exploration

(Working paper, ISSN 0226-7616; no. 44)
ISBN 0-88757-100-X

1. Gold mines and mining - Economic aspects.
2. Gold mines and mining - Economic aspects - Canada.
3. Prospecting - Economic aspects. 4. Prospecting - Economic aspects - Canada. I. Doggett, Michael. II. Queen's University (Kingston, Ont.). Centre for Resource Studies. III. Title. IV. Series: Working paper (Queen's University (Kingston, Ont.). Centre for Resource Studies); no. 44.

HD9536.A2M33 1989 338.2'341 C89-090748-X

Foreword

This paper represents research sponsored by the Centre for Resource Studies and aimed at improving the understanding of the conditions and issues facing the Canadian mineral industry, in order to assist in the formulation of policy decisions in industry and government. The Centre's working papers are offered for information and discussion, in an attempt to encourage feedback to the authors and additional research in mineral policy. Opinions presented are those of the authors, and do not necessarily represent the views of the Centre or its sponsors.

Acknowledgements

We would like to thank the following for their contributions to this paper: Michel Bilodeau who provided the computer modelling and analysis; Donald Cranstone for his contribution to the Canadian gold supply data base; and Derek Kyle, Rob McDonald, Richard Viljoen, and Roy Woodall for helping with the international perspective. Don Law-West, Patrick MacCulloch, and George Miller read an earlier draft of the manuscript and made helpful comments which are gratefully acknowledged.

Table of Contents

Foreword / iii

Acknowledgements / iv

1. Introduction / 1
   - Setting / 1
   - Objective and Organization of Study / 1

2. Worldwide Gold Exploration / 2
   - Introduction / 2
   - Time Lags in Gold Supply / 2
   - Gold Mine Production / 2
   - Gold Exploration Expenditures / 3
   - Discovery and Depletion / 4
   - Dynamic Factors / 5

3. Potential for Wealth Creation / 6
   - Introduction / 6
   - Potential Value / 6
   - Evaluation Criteria / 6
   - Gold Exploration in Canada / 7
   - The 1946-85 Period / 8
   - Time Trends / 9

4. Break-Even Price Requirement / 12
   - Introduction / 12
   - The Break-Even Price of Gold / 12
   - Evaluation Procedure / 12
   - Gold Exploration in Canada / 13
   - The 1946-85 Period / 13
   - Time Trends / 13

5. Possible Reasons for Decline in Exploration Performance / 18
   - Effect of the Hemlo Discovery / 18
   - Bias in the Data Base / 18
   - Depletion Effects / 18
   - Inefficient Exploration / 18

6. Conclusion / 20

Bibliography / 21

The Authors / 22

Centre for Resource Studies / 23

CRS Publications / 24

List of Tables

1. Gold mine production in the non-communist world / 3

2. Estimated gold exploration expenditures in the non-communist world / 3

3. Estimated gold discovered as a proportion of gold mine depletion in the non-communist world / 4

4. Average cash flow characteristics associated with the discovery of an economic gold deposit in Canada, 1946-85 period / 8

5. Potential value of gold exploration in Canada / 8

6. Time trends in average cash flow characteristics associated with the discovery of an economic gold deposit in Canada/ 9

7. Time trends in potential value of gold exploration in Canada / 11

List of Figures

1. Time distribution of average cash flows associated with the discovery of an economic gold deposit in Canada, 1946-85 period / 9

2. Time trends in the distribution of average cash flows associated with the discovery of an economic gold deposit in Canada, 1946-81 and 1982-85 intervals / 10

3. Relationship between gold price and gold supply in Canada, 1946-85 period / 14

4. Relationship between average exploration expenditure and gold supply in Canada, 1946-85 period / 14

5. Relationship between average development expenditure and gold supply in Canada, 1946-85 period / 14

6. Relationship between average production cost and gold supply in Canada, 1946-85 period / 14

7. Summation of cost components to determine average total gold supply cost in Canada, 1946-85 period / 15

8. Relationship between average total cost and gold supply in Canada, 1946-85 period / 16

9. Gold price-cost interrelationship and the determination of break-even price requirement in Canada, 1946-85 period/ 16

10. Time trends in gold price-cost interrelationship and break-even price requirement in Canada / 17

1. INTRODUCTION

Setting

The spectacular rise in free market gold prices since the early 1970s from the fixed US $35 per ounce nominal price which prevailed from 1934 to 1968 has provided a worldwide stimulus for gold supply. Levels of investment in gold mining during the 1980s are unprecedented.

A new wave of exploration for gold is lifting production to heights that few, if any, forecasters had imagined possible a few years ago. In the 1980s gold has been the principal target of most mining company exploration programs. There is even some concern that new gold discoveries coming on stream over the next decade may oversupply the market and depress the gold price.

There are various reasons why we - as investors, prospectors, geologists, companies, and countries - explore for gold. The search for gold deposits is driven by the lure of gambling, tax credits, job creation, and scientific interest. As compelling as these motives may be, however, surely the most important and sustainable reason why we explore for gold is the hope of making money.

This raises an essential question: is gold exploration an economic investment and, more intrinsically, a wealth-creating activity? Those involved in gold exploration, if they think about this question at all, tend to believe that their endeavours are economically worthwhile. Considering the unprecedented amounts of money being expended on the search for gold deposits, the economic viability of gold exploration cannot simply be assumed by an act of faith. The present investment of billions of dollars should be justified in a more objective way.

Outside of the mining community, in society at large, concerns about the economic merits of gold exploration are of long standing, going back at least 200 years to the time of Adam Smith who considered that:

> Of all those expensive and uncertain projects which bring bankruptcy upon the greater part of the people who engage in them, there is none perhaps more perfectly ruinous than the search after new gold mines.[1]

While some in the mining business may view such concerns as misplaced and counterproductive, the issue is relevant and worthy of analysis.

Objective and Organization of Study

The purpose of this study is to examine the premise that gold exploration is economically worthwhile. While the illustrations provided are based on the Canadian experience, the issue and the approach have worldwide relevance.

Chapter 1 provides the broad setting for the study. The relationship between gold mine production and replenishment through exploration is examined in chapter 2. In chapter 3, the potential value of gold exploration is discussed and then considered in the context of the Canadian experience. Trends in the break-even price of gold are evaluated in chapter 4. Chapter 5 provides explanations for the economic trends delineated in the previous two chapters. Conclusions are presented in chapter 6.

---

[1] *An Inquiry into the Nature and Causes of the Wealth of Nations*, 1789.

2. WORLDWIDE GOLD EXPLORATION

Introduction

This chapter examines the future consequences of the discovery of large quantities of new gold brought on by the record levels of worldwide gold exploration expenditures in the 1980s.[2] Is there a limit to how much new gold can be found before we reach a state of oversupply? By "oversupply" we mean a rate of production that would reduce the price of gold to the "level of discomfort" for currently operating mines or, in other words, to the US $250 - $300 per ounce range.[3]

Time Lags in Gold Supply

The gold supply process is characterized by long time lags:

- between changes in the price of gold and gold exploration expenditures;
- between gold exploration expenditures and gold mine production;
- between changes in gold mine production and the price of gold.

Corporate exploration strategies do not immediately respond to changes in market price. Concerns that higher prices might be temporary have to be overcome by a perception of permanence. Thus, the rise of free-market gold prices from the early 1970s did not trigger significantly higher exploration expenditures until the end of the decade. On the other hand, gold exploration has increased dramatically during the 1980s, while the price has been mainly falling from its 1980 peak.

The time required for exploration success and mine development is one of the most substantial commitments made by mining companies. The total time from the inception of gold exploration programs to the start of production can extend from several years under favourable circumstances to ten or more years in more normal situations.

Consequently, worldwide increases in gold mine production associated with price rises from the early 1970s have been appreciable only since the mid-1980s.

Given these long time lags and the record levels of gold exploration activity in the 1980s, there is concern that we could be heading for oversupply in the 1990s unless bold new initiatives can stimulate the demand for gold.[4]

Gold Mine Production

Approximately 110,000 tonnes of gold have been mined in the world to date. As much as 90 percent of this total has been extracted since 1850, and 50 percent since 1950. South Africa has produced about 40 percent of the total, followed by the U.S.S.R. with 15 percent. Output from the other major producers has been significantly lower: the United States accounts for 9 percent, Australia and Canada for 6 percent each, and Brazil for 2 percent of the total.

More than 95 percent of the 110,000 tonnes of gold mined is estimated to be present in above-ground stocks.[5] These holdings include government gold reserves, gold in jewellery, privately held gold coin and bullion, and gold contained in other fabricated products.

Even with the unprecedented rise in free-market gold prices during the 1970s, gold mine production in the non-communist world in 1980 was the lowest

---

[2] It is beyond the scope of this paper to enter into a detailed discussion of the various other supply and demand factors which influence the gold price. It is acknowledged that primary gold supply is only one of several sources providing gold to the market. As well, it is generally conceded that short-term gold prices reflect the take-up of gold by investor demand which is in turn closely linked to macroeconomic factors such as exchange rates, inflation, interest rates, other commodity prices, etc. On the other hand, as new gold production pushes toward record levels, an examination of the relationship between new discoveries and future price is warranted.

[3] This definition of oversupply was proposed at a policy workshop on the outlook for gold convened by the Centre for Resource Studies in October, 1986. See *Long-Term Prospects for Gold Mining*, Proceedings no. 20, edited by B. Mackenzie and R. Gesing, Centre for Resource Studies, Kingston, 1987.

[4] This was the view of most participants at the policy workshop on the outlook for gold convened by the Centre for Resource Studies in October, 1986. Ibid.

[5] Gold-Economics Service, International Gold Corporation Limited.

since the second world war.[6] Production during the 1980-87 period is summarized in table 1. Despite the time lags, the discovery, extension, and rehabilitation of gold mines succeeded in lifting production from 959 tonnes in 1980 to 1373 tonnes in 1987, representing an average growth rate of about 5 percent per year. South Africa accounted for 58 percent of non-communist world production during this period, followed by Canada and the United States (7 percent each), Brazil (5 percent), and Australia (4 percent). A diverse group of other countries produced the remaining 19 percent.

Table 1
Gold mine production in the non-communist world
(tonnes)

Year	Australia	Brazil	Canada	South Africa	United States	Other	Total
1980	17	35	52	675	31	149	959
1981	18	35	53	658	44	173	981
1982	27	35	66	664	45	191	1028
1983	31	59	73	680	63	208	1114
1984	39	62	86	683	66	226	1162
1985	59	72	90	672	79	261	1233
1986	75	67	106	640	118	284	1290
1987	108	84	120	607	155	299	1373
Total	374	449	646	5279	601	1791	9140

Source: *Gold 1988*, Consolidated Gold Fields.

Production of 1665 tonnes of gold is projected for 1991, equivalent to a continuation, for the 1987-91 period, of the 5-percent average annual increase from 1980-87.[7] Gold mine production appears to be well established on an exponential growth curve.

[6] In the short term, within existing capacity, there is a negative relationship between the gold price and gold production. An increase in the price of gold results in lowering the cut-off grade and, consequently, the average grade mined and the amount of gold recovered.

[7] *World Mine Production of Gold 1987-1991*, The Gold Institute, September 1988.

Gold Exploration Expenditures

Gold exploration expenditures in the non-communist world during the 1980-87 period, expressed in constant 1987 Canadian dollars, are presented in table 2.[8] These order-of-magnitude estimates show that the worldwide level of gold exploration activity has increased from $0.5 billion in 1980 to $2.3 billion in 1987, equivalent to an average annual growth rate of 24 percent.

Table 2
Estimated gold exploration expenditures in the non-communist world
($ million)

Year	Australia	Brazil	Canada	South Africa	United States	Other	Total
1980	74	18	152	27	174	62	507
1981	146	50	230	31	298	64	819
1982	177	55	222	35	273	84	846
1983	160	68	226	32	272	83	841
1984	222	87	302	76	290	149	1126
1985	225	98	379	115	203	384	1404
1986	275	117	551	129	209	464	1745
1987	340	133	850	222	332	465	2342
Total	1619	626	2912	667	2051	1755	9630

Of the $9.6 billion total, Canada accounts for 30 percent, followed by the United States (21 percent), Australia (17 percent), South Africa and Brazil (7 percent each), with the remaining 18 percent invested in other countries. These breakdowns, it should be noted, are quite different than the respective country shares of gold mine production. Future exploration potential is, of course, not necessarily related to past production. The relatively low exploration expenditure total for South Africa is, however, misleading because gold exploration on the

[8] This information has been obtained from government statistics (Canada, Australia), private company surveys (United States, South Africa, Brazil), and subjective estimates (most of the "other" countries).

Witwatersrand, relieved of most of the high-cost primary stages, can mainly be concentrated on drilling prospective ground for gold reef extensions.[9] The high expenditures in Canada and Australia have been encouraged, in part, by government incentives - flow-through-share tax write-offs, and tax-exempt status for gold mine income, respectively.

Discovery and Depletion

Production from such nonrenewable resources as gold deposits represents depletion. For producing gold mines, companies and countries, therefore, a certain level of exploration expenditure is required each year just to maintain currently installed productive capacity.

The possibility of an oversupply of gold in the 1990s resulting from the discovery of economic deposits can be examined by linking current levels of exploration expenditure and mine production. We would like to know how much gold is being discovered relative to the gold being depleted in the course of production.

In order to make this connection in a general way, an assumption is required concerning the typical discovery cost per ounce of gold recoverable from economic deposits. Evidence from Canada, Australia, and the United States suggests that exploration expenditures, on an unadjusted basis disregarding time value, probably average between $30 and $60 per ounce.

Applying unit discovery costs of $30, $45, and $60 per ounce to the mine production and exploration expenditure figures given in tables 1 and 2, estimates have been made of ounces of gold discovered as a proportion of gold mine depletion. Results are presented in table 3.

[9] For example, in 1987, there were about 150 rigs working in the Witwatersrand basin, drilling exploratory and delineation boreholes, each to a depth of several thousand metres.

Table 3
Estimated gold discovered as a proportion of gold mine depletion in the non-communist world

	Exploration expenditure per ounce		
Year	$30	$45	$60
1980	0.55	0.37	0.27
1981	0.86	0.58	0.43
1982	0.85	0.57	0.43
1983	0.78	0.52	0.39
1984	1.01	0.67	0.50
1985	1.18	0.79	0.59
1986	1.40	0.94	0.70
1987	1.77	1.18	0.88
Average	1.09	0.73	0.55

In summary:

- the discovery of gold in 1980 apparently was sufficient only to replace between 27 percent and 55 percent of the gold mined in that year;
- by 1987, exploration expenditures were at a high enough level to discover an amount of gold equivalent to between 88 percent and 177 percent of mine production;
- the discovery of gold in the overall 1980-87 period is estimated to be sufficient to replace between 55 percent and 109 percent of the gold depleted from ore reserves at operating mines.

On this basis, there is little evidence to support the premise that there will be an oversupply of gold in the 1990s resulting from successful exploration during the 1980s.

Dynamic Factors

What, then, explains the actual and anticipated growth in gold mine production through the 1980s and into the 1990s? What is the long-term potential for gold exploration?

First, the growth in gold mine production that is taking place may be attributable as much or more to the effect of higher prices on cut-off grade than to new discoveries. While there is a negative relationship between the gold price and gold production in the short term within existing capacity, there are opportunities to expand capacity in the medium term from known but previously uneconomic reserves.

Second, much of the record investment taking place during the 1980s is in the nature of rehabilitation for an industry that, in most parts of the world, had been suffering a steady decline throughout the 1950s, 1960s, and 1970s. Despite the current prosperity of gold mining, the historic trend will not be easily or quickly reversed.

Third, increases in mine production arising from small, superficial deposits with short lives will be difficult to sustain beyond the next few years. For example, about half of Australia's gold production comes from small mines with reserves of less than five years.

Fourth, it is unlikely that the worldwide level of gold exploration expenditure during the mid-1980s, in the order of $2.3 billion in 1987, can be sustained. Also, the inevitable transition in exploration focus from re-exploration of known occurrences to primary targets will no doubt increase discovery costs.

In the long run, it will be a challenge to discover and delineate the ore reserves required to maintain present rates of gold mine production. In this respect, the potential for gold exploration is positive.

3. POTENTIAL FOR WEALTH CREATION

Introduction

The previous chapter established that current levels of exploration are unlikely to oversupply the gold market. While this result provides encouragement for gold exploration, it is not sufficient to justify investment. An assessment is also required of the economics of exploring for gold.

The gold supply process proceeds from exploration through development to production. Investment starts with the search for economic gold deposits. Thus, exploration occupies a strategic up-front position in the supply process.

Gold exploration cannot be justified as an end in itself. The economic viability of gold exploration is determined by the costs, risks, and returns associated with the three-phase supply process.

Potential Value

The potential of gold exploration for wealth creation is defined here as the difference between the revenues realized from gold production and all the associated costs, including an allowance for the cost of capital. Potential value represents the increase in real wealth that results from investing in gold exploration from the viewpoint of society as a whole, and indicates what is available for sharing between companies and governments prior to taxation and other public policy considerations.

Evaluation Criteria

The potential value of gold exploration can be conveniently portrayed by the time distribution of average cash flows associated with the discovery of an economic gold deposit. The following two indicators, derived from this type of distribution, are applied in this paper.

1. Expected Value per Economic Discovery

An exploration expenditure E is required on average for the discovery and delineation of an economic deposit, yielding an average return R.

Thus:

$$EV = R - E$$

where

EV = expected value per economic discovery;

R = average net return from development and production associated with the discovery of an economic mineral deposit;

E = average exploration cost required to find and delineate an economic deposit.

To make a valid comparison, R and E are expressed as time-adjusted values at the start of exploration, using a cost-of-capital estimate for the investment as the discount rate.

2. Expected Rate of Return

The expected rate of return on investment can also be derived from the time distribution of average cash flows for an economic deposit. By definition, rate of return is the discount rate that equates the present value of the positive cash flows with the present value of the funds invested. In economic terms, rate of return represents the average percentage annual return that gold exploration is expected to yield over the three-phase supply cycle.

Empirical assessment of the potential of gold exploration for wealth creation is based on historical trends. One central assumption is necessary if such results are intended to support policy and planning: the past can tell us something useful about the future. In order to make this type of assessment, actual experience over a relevant historical time period is documented and then, for appraisal purposes, placed in the context of current outlook conditions. The end result is an evaluation of the average cash flow distribution for an economic gold deposit and the associated potential value indicators.[10]

[10] For further information on the economic concepts, criteria, and methodology applied, the interested reader is referred to B.W. Mackenzie and M.L. Bilodeau, *The Economics of Mineral Exploration in Australia*, Australian Mineral Foundation, Adelaide, 1984; and B. Mackenzie and R. Woodall, *Mineral Exploration Economics: The Search for Base Metals in Australia and Canada*, working paper no. 40, Centre for Resource Studies, Kingston, 1987.

The illustrative assessments which follow are based on the search for gold deposits in Canada during the 40-year period 1946-85. Within the overall time-frame, more specific appraisals are made for the 1946-81 and 1982-85 intervals to discern time trends in the economics of gold exploration. While many breakdowns of the 40-year period are possible, there are several reasons for choosing the 1946-81 and 1982-85 intervals in this study. The intervals split the total gold exploration expenditure for the period into approximately equal parts. As well, the intervals selected represent distinct eras of gold exploration in Canada.

Until the postwar years, gold was the keystone of the Canadian mineral economy, a perennial leader in the value of all metals and mineral commodities produced. Most of the 1946-81 study interval is associated with generally declining activity in gold exploration as fixed prices, rising costs and other more attractive commodity targets combined to shift the focus of exploration away from gold.

The spectacular rise in free-market gold prices from the early 1970s provided a stimulus for the recovery of gold mining in Canada, but corporate exploration budgets and programs were generally slow to respond. The slow response reflected both concern that the higher prices might be temporary and the time-consuming reorientation of geologic expertise and exploration techniques from other metals to gold. The new era in gold exploration in Canada can be considered to have begun in 1982, when the exploration emphasis shifted back to gold. For the first year since 1951, more money was spent on gold exploration in Canada than on base metal exploration. This change was brought on by several factors:

- peak gold prices in 1980, averaging US $613 per ounce;
- depressed nonferrous metal markets;
- discovery of the Hemlo deposit in 1981;
- advent of flow-through-share financing for mineral exploration in 1983.[11]

For purposes of assessing the potential of gold exploration in Canada, money values are expressed in constant 1987 Canadian dollars.[12] An 8-percent cost of capital is applied to time-adjust the cash flow estimates.

One aspect of the evaluation is to determine which of the gold deposits discovered in the past would be economic under today's conditions. For this purpose, an economic deposit is defined as a discovery that realizes a total revenue of at least $20 million and a rate of return of at least 8 percent.

The potential value of gold exploration is assessed using a gold price of $600 per ounce (equivalent to US $450 per ounce). While this will no doubt be viewed as an optimistic price outlook today (1989),

---

[11] Flow-through shares were made attractive through changes in tax legislation in 1983 and since that time have evolved as an important source of equity financing for the Canadian mining industry. Flow-through shares can be defined as an interest acquired in a mining venture in which the tax deductions resulting from the expenditure of the invested funds are attributable (or "flow through") to the original investor on whose behalf the activity is undertaken. More specifically, under current Canadian tax laws, the tax deductions resulting from exploration activities can be attributed to the investor of equity funds in mining. See B.A. Kalymon, *Flow-Through Share Financing*, working paper no. 39, Centre for Resource Studies, Kingston, 1987.

The tax deductions associated with flow-through shares have included a 33 1/3 percent mineral exploration depletion allowance. Tax reform proposals announced by the federal government in June 1987 incorporated a provision whereby this depletion allowance would be phased out. Then, in May 1988, the federal government announced the Canadian Exploration Incentive Program whereby it makes cash payments to eligible exploration expenses, starting in 1989. This new program is intended to maintain the federal government incentive for flow-through-share funding of gold exploration.

[12] The average 1987 exchange rate of 0.75 US dollars per Canadian dollar can be used to convert results to United States dollars.

it probably provides a reasonable overall representation of market perceptions held during the 1980s.

An annual exploration budget of $5 million, considered to be among the most efficient rates of expenditure, is applied in determining the average exploration period required to discover an economic deposit.

The 1946-85 Period

Gold exploration expenditures in Canada for the 1946-85 period total approximately $2.4 billion. As a result of this activity, 134 gold deposits that could possibly satisfy our "economic deposit" definition were discovered.[13]

For the specified evaluation conditions, 103 of the 134 discoveries are found to be economic. The cost and revenue characteristics of these economic deposits are combined with the total exploration expenditure estimate to assess the time distribution of average cash flows for an economic deposit. The cash flow distribution is presented in figure 1 and summarized in table 4. The total cash flow generated by an economic deposit averages $177 million.

Table 4
Average cash flow characteristics associated with the discovery of an economic gold deposit in Canada, 1946–85 period

Characteristic	1946–85
Time periods (years):	
Exploration phase	5
Development phase	3
Production phase	30
Undiscounted values ($ million):	
Revenue	389
Exploration expenditure	23
Development capital cost	34
Production cost	155
Cash flow	177

[13] For a listing of these discoveries, see Appendix II, pp. 160-163, in D. Cranstone, B. Mackenzie and M. Doggett, "Long-Term Break-Even Price for Canadian Gold Supply" in *Long-Term Prospects*.

Based on the cash flow results portrayed in figure 1, assessments are made for the potential value criteria (table 5).

Table 5
Potential value of gold exploration in Canada

Parameter	1946–85
Total exploration expenditure ($ million)	2396
Number of economic discoveries	103
Average exploration expenditure (E, $ million)	19
Average return (R, $ million)	54
Expected value (EV, $ million)	35
Expected rate of return (percent)	17

As shown, gold exploration experience in Canada represents an expenditure of approximately $2.4 billion, the result of which has been the discovery of 103 economic deposits. The average cost required to find and delineate an economic deposit is therefore about $23 million, equivalent to $19 million (E) when discounted at 8 percent to the start of the exploration phase. The reward for this exploration expenditure is an average return of $54 million (R) for each economic discovery, also expressed as a present value at the start of exploration. Consequently, the expected value of exploration per economic discovery is $54 million minus $19 million, or $35 million (EV). This means that, on average, under the assumed conditions, $35 million of new wealth is associated with the discovery of an economic gold deposit. Alternatively, the potential value of gold exploration can be expressed as a 17-percent expected rate of return in relation to the 8-percent cost-of-capital rate.

These results indicate that, for the assumed conditions, gold exploration is certainly an economic investment, offering potential to increase substantially the wealth available to Canadian society.

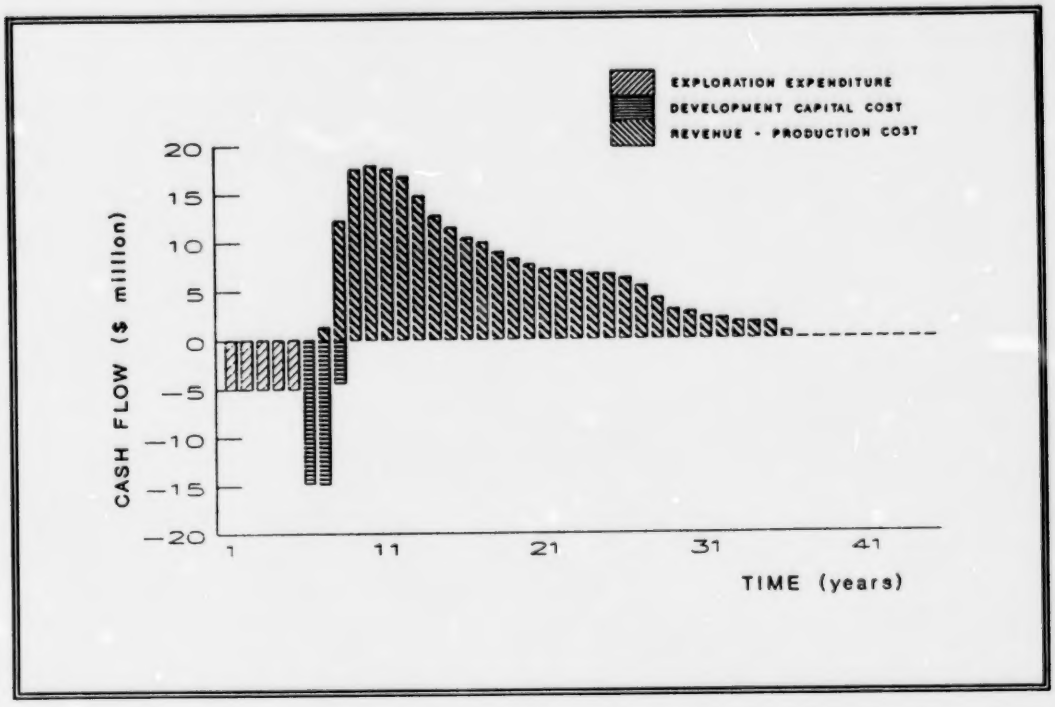

Figure 1. Time distribution of average cash flows associated with the discovery of an economic gold deposit in Canada, 1946-85.

Time Trends

Gold exploration performance in Canada during the 1946-81 and 1982-85 intervals are compared here to illustrate trends in results within the overall study period.

The $1.3 billion invested in gold exploration during the 36-year interval 1946-81 accounts for 53 percent of the total expenditure. Exploration carried out during this time resulted in the discovery of 95 significant gold deposits or, in other words, 71 percent of the possible economic discoveries made during the 1946-85 period. In comparison, the four-year interval 1982-85 (only 10 percent of the overall timeframe) accounts for the remaining 47 percent of the gold exploration expenditures (about $1.1 billion) and for the other 39 possible economic discoveries (only 29 percent of the period total).

Under the assumed appraisal conditions, the time distribution of average cash flows for each interval is assessed as portrayed in figure 2 and summarized in table 6. Table 7 compares the resulting potential value indicators.

Table 6
Time trends in average cash flow characteristics associated with the discovery of an economic gold deposit in Canada

Characteristics	1946–81	1982–85
Time periods (years):		
Exploration phase	4	8
Development phase	3	3
Production phase	30	23
Undiscounted values ($ million):		
Revenue	447	248
Exploration expenditure	17	38
Development capital cost	37	26
Production cost	174	110
Cash flow	219	74

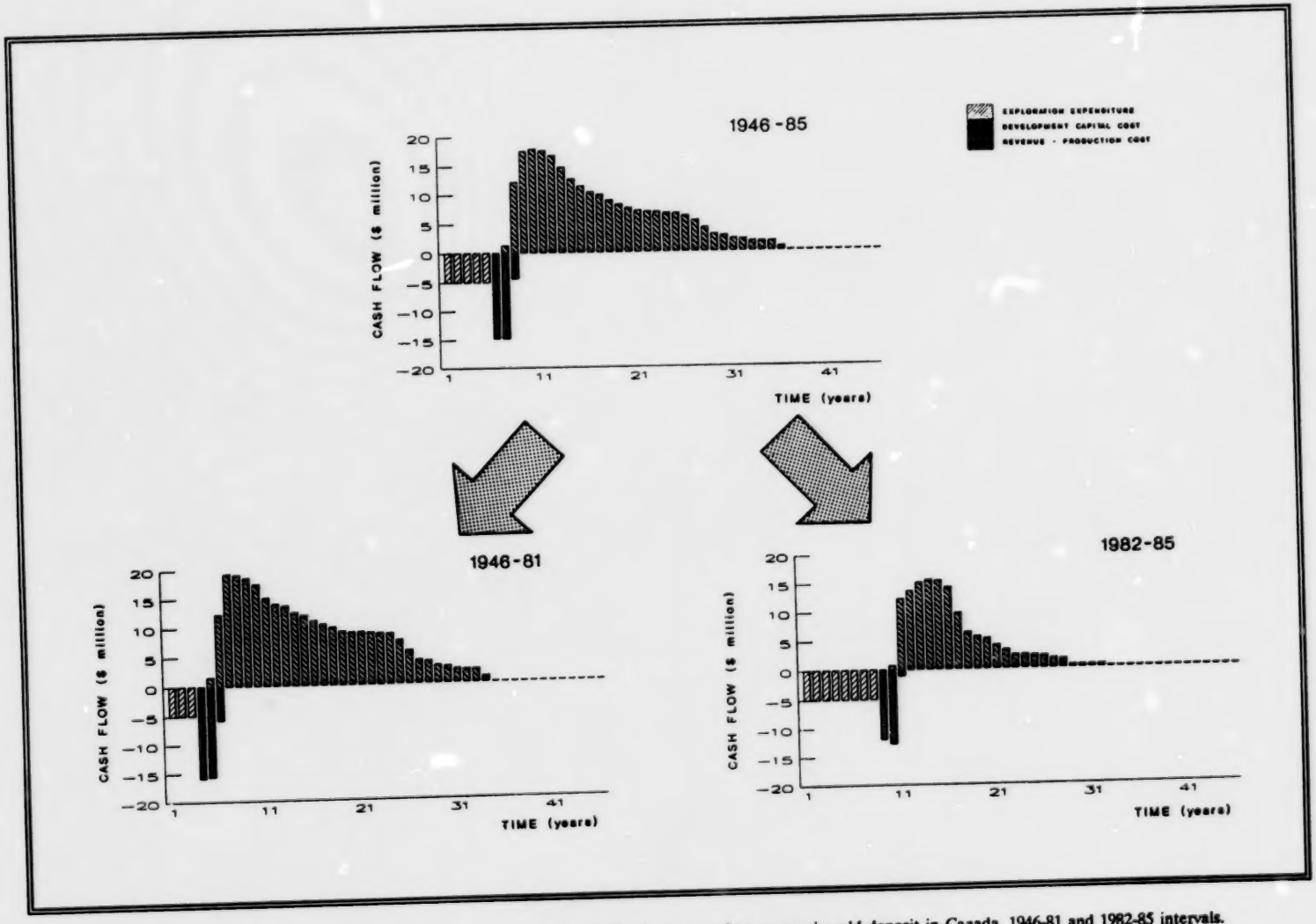

Figure 2. Time trends in the distribution of average cash flows associated with the discovery of an economic gold deposit in Canada, 1946-81 and 1982-85 intervals.

Table 7
Time trends in potential value of gold exploration in Canada

Parameter	1946–81	1982–85
Total exploration expenditure ($ million)	1,267	1,129
Number of economic discoveries	73	30
Average exploration expenditure (E, $ million)	15	28
Average return (R, $ million)	67	30
Expected value (EV, $ million)	52	2
Expected rate of return (percent)	21	9

A disturbing deterioration in the economic performance of gold exploration in Canada is apparent. The average expenditure required to find and delineate an economic gold deposit (E) is found to have increased from $15 million to $28 million. At the same time, the average return for an economic discovery declined from $67 million to $30 million. Consequently, the expected value per economic discovery is shown in table 7 to deteriorate from $52 million for the 1946-81 interval to only $2 million during 1982-85. Similarly, the expected rate of return on investment declines from 21 percent to 9 percent in relation to the 8-percent break-even cost of capital.

These time trends suggest that gold exploration in Canada is changing from a highly valued wealth-creating activity to a generally marginal economic proposition. A discussion of possible reasons for the observed falling off in gold exploration performance is deferred until chapter 5 so that the break-even results from chapter 4 can be incorporated.

4. BREAK-EVEN PRICE REQUIREMENT

Introduction

The preceding assessments of the potential value of gold exploration are based on a gold price of $600 per ounce.[14] While this assumption may be regarded as too optimistic in 1988-89, it appeared reasonable a year or two ago, and would likely have been viewed as unduly conservative in the heady days of 1980-81. The irrational tendency to tie long-term projections to current prices is symptomatic of how little we know about the future.

The relevant timeframe for the $600 projection only begins some 5 to 10 years into the future. This is illustrated by the position of the production period in figures 1 and 2. Thus, when evaluating the economics of gold exploration, we don't really care what the price of gold will be in 1990, 1992, or even 1995. The relevant gold prices are the ones which will prevail when the economic gold deposits currently awaiting discovery are in a position to produce and sell gold, most likely from the mid-1990s to the turn of the century and beyond.

The Break-Even Price of Gold

Even with the best possible market research expertise, it is extremely difficult, if not impossible, to meaningfully predict the price of gold so far into the future. We would be surprised if actual gold prices over the relevant timeframe for exploration planning were to average out anywhere close to the projected $600 per ounce.

Under such conditions of uncertainty, a related question can be usefully addressed: what minimum acceptable, or break-even, price of gold would be required to economically justify the extraordinarily high level of investment in gold exploration in recent years? The reason for making this type of assessment is that it should be somewhat less difficult to make a meaningful judgment concerning which side of the break-even point the uncertain future gold price will be on than to provide a more specific prediction.

The break-even gold price requirement can be appraised by analyzing the cost structure of the gold supply process. There are three relevant cost components:

- exploration expenditures;
- development capital costs;
- production costs.

With respect to exploration and development costs, time value differences between the years in which expenditures are incurred and the years when the associated gold content is recovered and sold must also be accounted for.

Evaluation Procedure

The methodology used to evaluate the break-even gold price requirement is the reverse of that previously employed to assess the potential value of gold exploration. Instead of assuming a gold price and appraising the potential for wealth creation, the price of gold that yields a minimum acceptable bottom-line result is determined. In essence, the methodology is as follows.

1. A minimum acceptable economic outcome is established.
2. A wide range of possible gold prices is specified.
3. The economics of the gold supply process is evaluated for possible gold prices within the specified range.
4. The relationship between gold price and gold supply is assessed.
5. Exploration expenditures, development capital costs, and production costs per ounce are evaluated as functions of gold price and gold supply.
6. The three cost components are summed to delineate the average total cost per ounce function.
7. The gold price and average total cost relationships are compared to determine the break-even gold price requirement.

[14] Once again, note that money values are expressed in constant 1987 Canadian dollars. To convert to United States dollars, the average 1987 exchange rate of 0.75 US dollars per Canadian dollar can be applied.

Gold Exploration in Canada

To illustrate the application of this methodology, we once again consider the case of gold exploration in Canada. The data base and evaluation conditions are identical to those outlined for the potential value assessments (chapter 3) except that the gold price is now varied from $300 to $700 per ounce rather than being fixed at $600 per ounce. The minimum acceptable outcome is assumed to be an 8-percent rate of return on investment, equivalent to the 8-percent cost of capital previously employed.

The 1946-85 Period

The empirical relationship between gold price and gold supply is shown in figure 3. As the gold price is increased from $300 to $700 per ounce, the gold recoverable from economically viable discoveries is shown to increase from about 34 million ounces (1060 tonnes) to 74 million ounces (2300 tonnes).[15]

The cost structure of Canadian gold supply during the 1946-85 period is portrayed in figures 4 to 8. As the price is increased through the specified range, the average exploration expenditure required to discover and delineate a recoverable ounce of gold in an economic deposit falls from $462 to $79 as shown in figure 4. This reduction in discovery costs is attributable to two factors:

- spreading the $2.4 billion of total expenditures over 74 million ounces as compared to 34 million ounces;
- a decrease in the time cost of exploration arising from the greater number of discoveries which would be economic at higher prices and the consequent shortening of the average exploration period per economic discovery.

At the same time, development expenditures and production costs are shown to rise (figures 5 and 6) from $64 to $100 per ounce, and from $168 to $262 per ounce respectively. These costs increase as a function of the price of gold because of the effect of higher prices on lowering cut-off grades and, consequently, average grades mined.

[15] 1 million ounces = 31.1034 tonnes.

The summation of these three time-adjusted cost components is illustrated in figure 7. The resulting average total cost curve, reproduced in figure 8, is found to be a U-shaped function of gold supply. The minimum average cost is $416 per ounce. About 54 million ounces (1680 tonnes) of gold mine production would ultimately be supplied at this point.

The relationship between the gold price curve and the average total cost curve is portrayed in figure 9. The break-even gold price requirement is found to be $435 per ounce. At this point, about 57 million ounces (1770 tonnes) of gold would be recovered from deposits discovered during the 1946-85 period. At the $435 per ounce price, the expected value of gold exploration per economic discovery is zero and the expected rate of return on investment is 8 percent.[16]

Time Trends

The same evaluation procedure has been more specifically applied to gold exploration in Canada during the 1946-81 and 1982-85 intervals. The resulting gold price and average total cost relationships are presented in figure 10. The breakeven price requirement is shown to increase with time from $380 to $585 per ounce.

An alarming deterioration in the economic performance of gold exploration in Canada is again evident. The break-even gold price requirement has apparently increased by more than $200 per ounce from 1946-81 to 1982-85. Possible explanations for this negative trend are considered in chapter 5.

[16] For purposes of comparing the results presented in figures 3 to 8 with the potential value assessments discussed in the preceding chapter, the costs associated with a gold price of $600 per ounce are as follows.

	$ per ounce
Exploration expenditure	84
Development expenditure	94
Production cost	249
Average total cost	427

The surplus of ($600 - 427) = $173 per ounce is related to the $35-million expected value per economic discovery and 17-percent expected rate of return previously assessed.

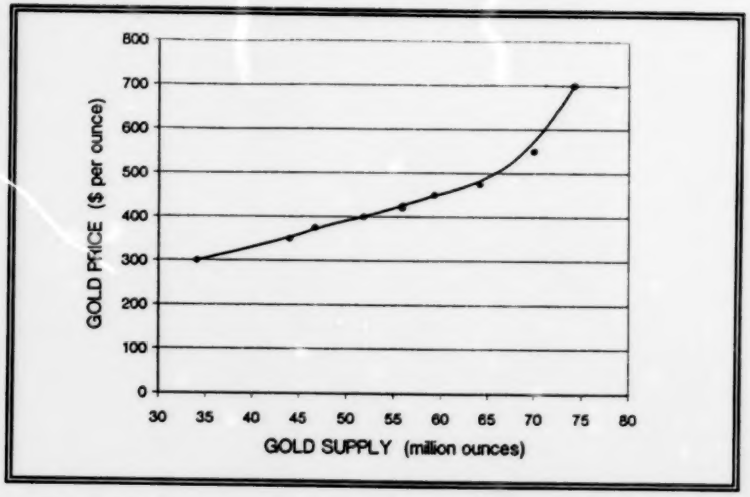

Figure 3. Relationship between gold price and gold supply in Canada, 1946-85 period.

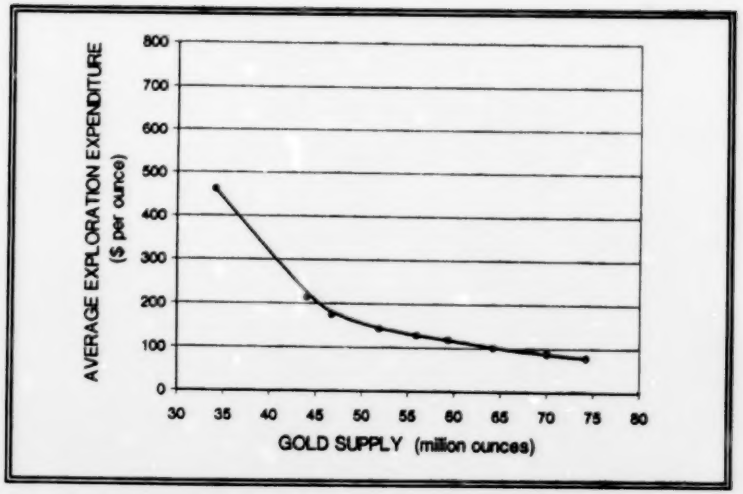

Figure 4. Relationship between average exploration expenditure and gold supply in Canada, 1946-85 period.

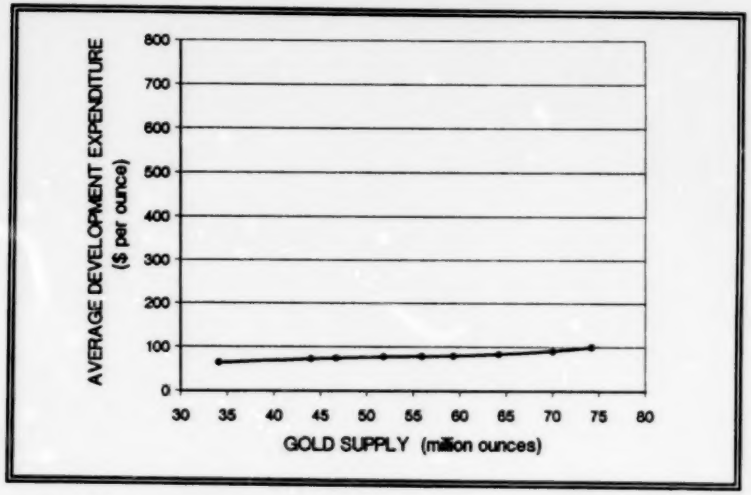

Figure 5. Relationship between average development expenditure and gold supply in Canada, 1946-85 period.

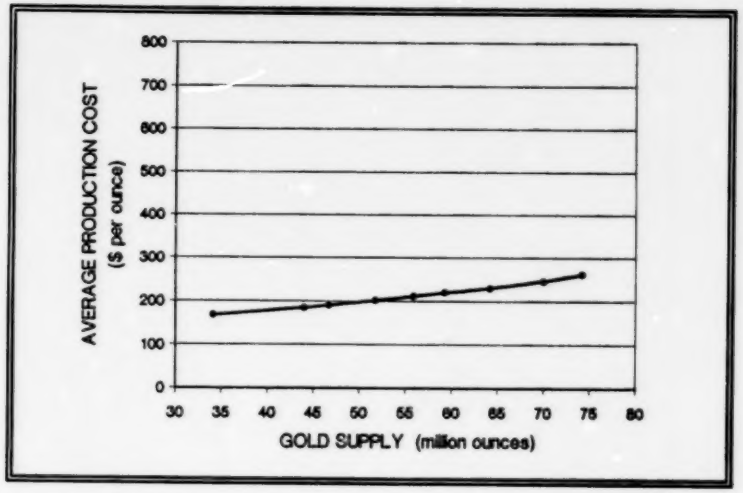

Figure 6. Relationship between average production cost and gold supply in Canada, 1946-85 period.

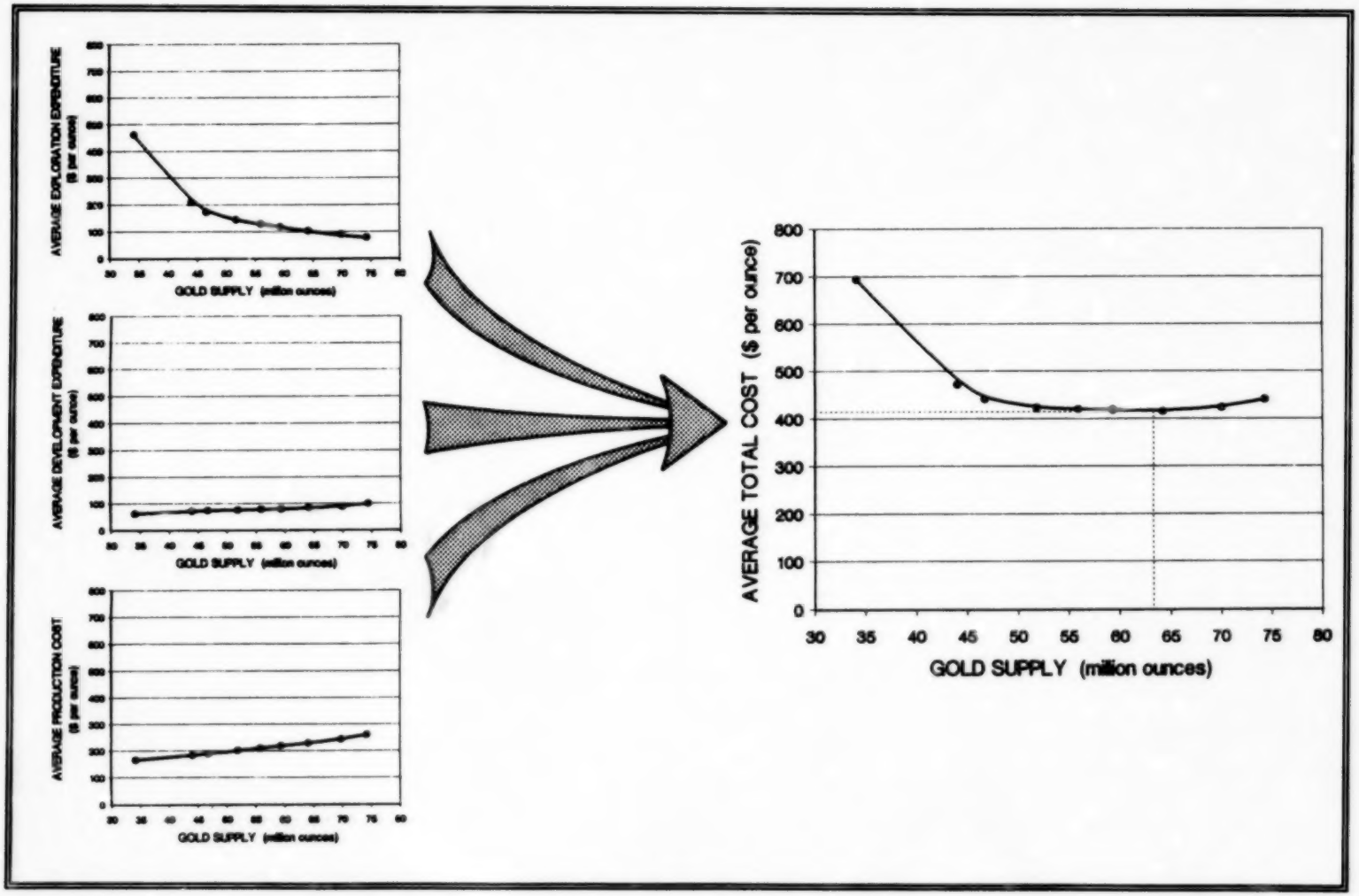

Figure 7. Summation of cost components to determine average total gold supply cost in Canada, 1946-85 period.

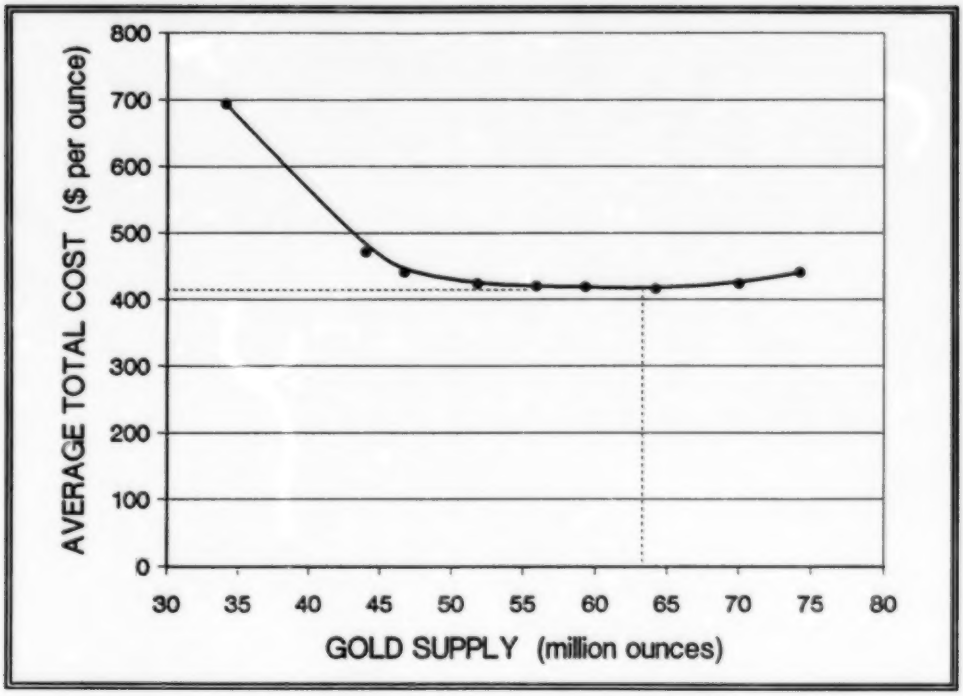

Figure 8. Relationship between average total cost and gold supply in Canada, 1946-85 period.

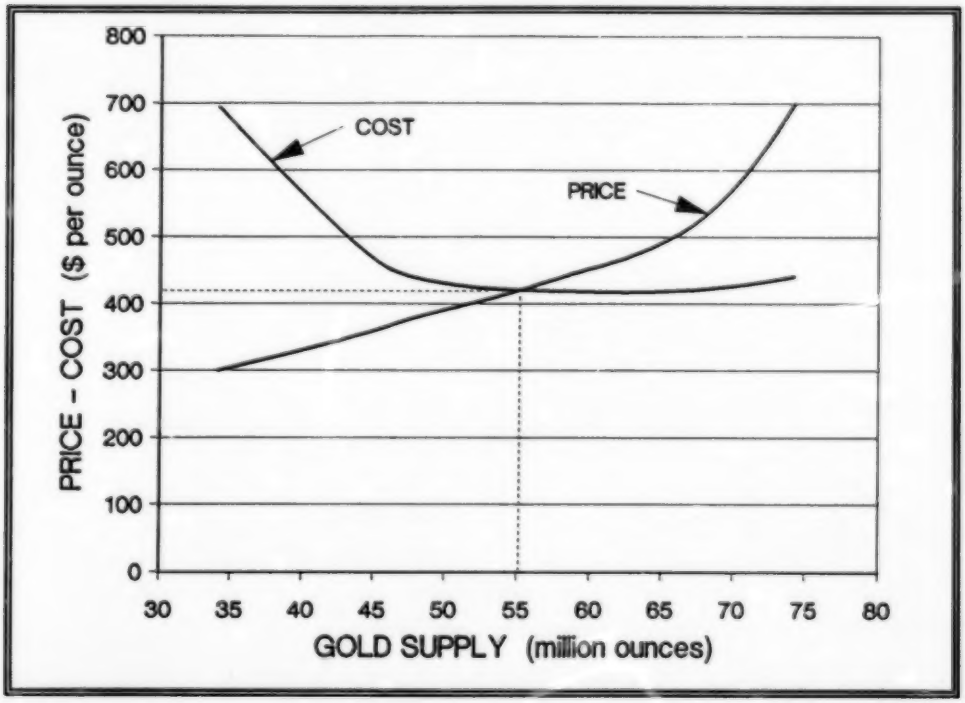

Figure 9. Gold price-cost interrelationship and the determination of break-even price requirement in Canada, 1946-85 period.

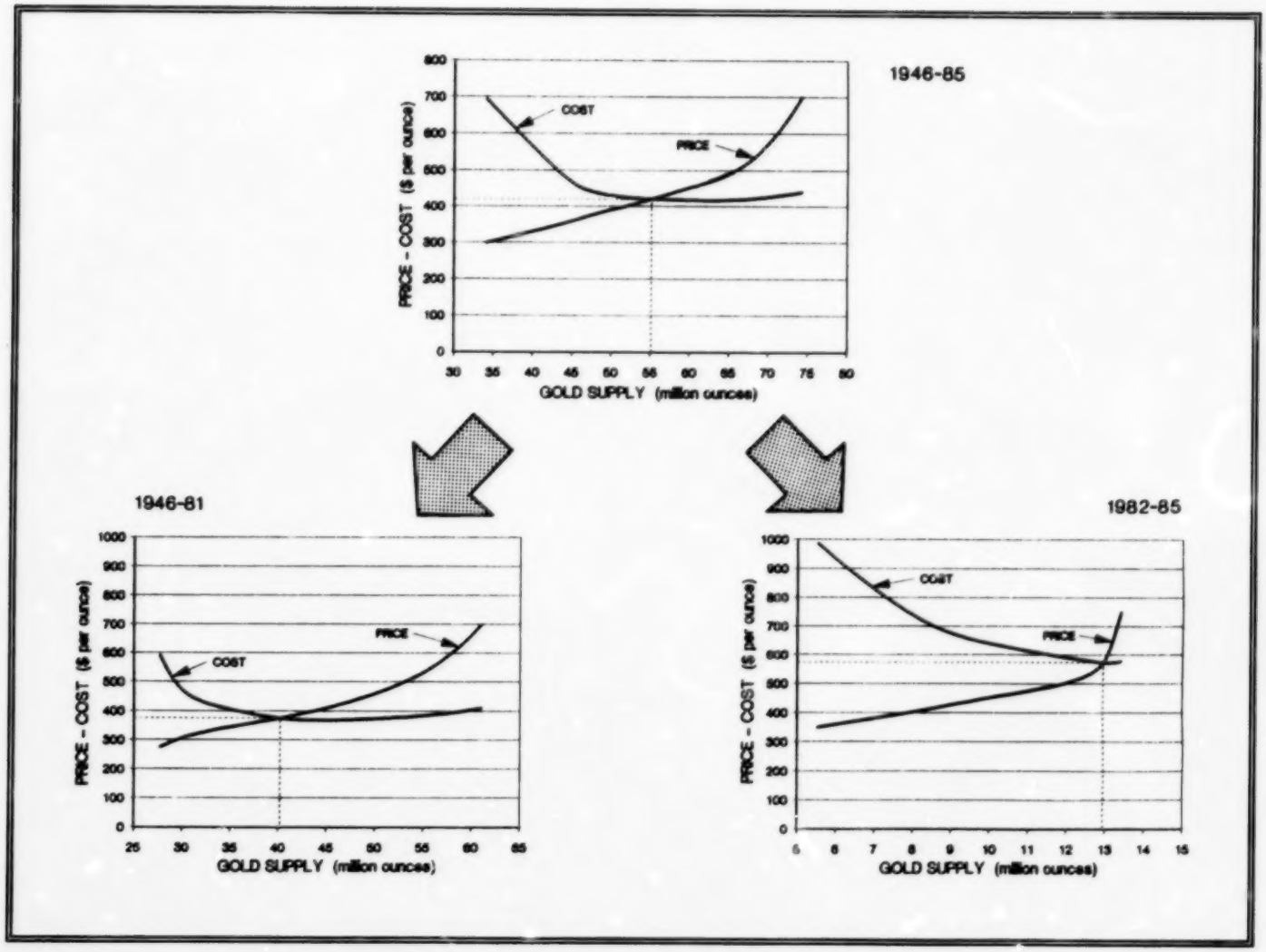

Figure 10. Time trends in gold price-cost interrelationship and break-even price requirement in Canada.

5. POSSIBLE REASONS FOR THE DECLINE IN EXPLORATION PERFORMANCE

As evidenced by the time trends in potential value (figure 2, tables 6 and 7) and the break-even price requirement (figure 10), there has been a major decline in gold exploration performance in Canada from 1946-81 to 1982-85. A number of reasons are suggested below to explain this falling-off in performance.

Effect of the Hemlo Discovery

Hemlo is included in the first time interval because the recognition of this exceptional deposit is one of the main reasons for the phenomenal growth in gold exploration which has taken place in Canada. If Hemlo is hypothetically removed from the 1946-81 record, the expected value of gold exploration per economic discovery for this time interval would be $30 million rather than $52 million, and the expected rate of return on investment would decrease from 21 percent to 18 percent. Nevertheless, these reduced values are still much higher than the $2 million expected value and 9 percent rate of return evaluated for the 1982-85 interval.

The break-even results are also affected by the Hemlo discovery. As a result of once again removing this deposit, the break-even gold price requirement for the 1946-81 interval is found to increase from $380 to $440 per ounce. Even without the Hemlo discovery, however, the break-even gold price increases by $145 per ounce between 1946-81 and 1982-85.

Thus, while the Hemlo discovery certainly does have a substantial impact on gold exploration potential, it by no means fully explains the sharp drop in performance assessed between 1946-81 and 1982-85.

Bias in the Data Base

There is a tendency to undervalue cash flow estimates, particularly for the deposits discovered most recently. If the historical timeframe is brought too close to the present, some recent discoveries may not be considered at all, simply because they are not generally recognized at the time the assessment is made. Otherwise, the bias is most pronounced with respect to ore reserve tonnage estimates for the most recent discoveries included in the evaluation.

This problem can be eased by periodic updating. Our gold deposit data base was last revised at the end of 1987. We plan to do so again in early 1990.

We have examined elsewhere the effect of this bias by applying ore reserve multipliers, estimated for each deposit, to allow for the difference between gold content estimated on the basis of initial delineation of a discovery and the amount of gold ultimately recoverable.[17] While the recoverable gold content for the deposits evaluated as economic was found to increase by 74 percent, the corresponding decrease in the break-even gold price was less than 6 percent. The time-adjusted effect of the multipliers is relatively modest because the added ounces act mainly to extend mine life, adding years of production quite far out in the future.

Depletion Effects

To the extent that gold exploration, guided by geoscience concepts and skills, is a systematic process, those deposits that are largest, of highest grade, closest to surface, or nearest to infrastructure should tend to be discovered first. Deposits that are lower grade, smaller, more remote, or harder to find come later. This is no doubt one of the reasons for the observed decline in exploration performance.

With the rise in free-market gold prices from the early 1970s, the most obvious and attractive targets for gold exploration have been the known occurrences in old mining districts. While there are obviously many opportunities of this type in Canada, they are being systematically followed up and depleted. Canadian gold exploration in the 1980s appears to be in a transition period from relatively low-cost and low-risk re-evaluation of known occurrences to higher-cost and higher-risk primary exploration programs. Although a considerable amount of money is still being spent on exploration in the vicinity of old mines, the higher break-even gold price requirement assessed for 1982-85 no doubt reflects in part this transition to higher-cost primary exploration activities.

Inefficient Exploration

Because exploration is a high-risk activity, a large number of sequential steps are necessary to limit the cost of failure. In each step, the general approach should be to spend a little money, gather a little information, analyze and think about the results, then decide what best next to do. By limiting the cost of

[17] The effect of ore reserve multipliers is presented in Cranstone, Mackenzie and Doggett, op.cit., p. 147.

failure, a phased approach to exploration conserves scarce human and financial resources so that they can be concentrated on the few promising opportunities.

Exploration efficiency measures the relationship between exploration expenditures and the value of deposits discovered as the result of that exploration.

One possible explanation for observed exploration inefficiency lies in the exploration planning of most mining companies. Since 1982, there has tended to be an overemphasis on gold exploration with exploration budgets approved more readily for gold projects and all geologic personnel, regardless of expertise or background, concentrating on gold projects.

Exploration efficiency is particularly sensitive to government policy because at the time exploration plans are formulated, there is the widest possible scope for deciding how and where to explore. Given the high-risk nature of gold exploration, it is imperative that government policies encourage efficient exploration.

The federal government's flow-through share policy has made the after-tax cost of exploration very cheap. While this policy certainly encourages exploration expenditure, it provides no particular incentive for efficient, successful exploration.[18]

---

[18] Flow-through money accounted for 35 to 40 percent of total gold exploration expenditures during the 1982-85 interval. While these funds are sufficient to have had an appreciable impact on the economic results calculated in this study, the most dramatic increases in flow-through share funding occurred after the end of the study timeframe. When the current work is updated to include these more recent expenditures, we anticipate that flow-through funds will have a much more profound effect on the economics of gold exploration in Canada.

6. CONCLUSION

The future market consequences of present success in gold exploration have been examined on a global basis. There are certainly grounds for optimism. It will be much more difficult than generally thought to oversupply the gold market in the longer term through successful exploration.

From this point of view, the future price of gold may be maintained well above the US $250 - $300 per ounce "level of discomfort" for current operations. Also, the world's gold producers are beginning to take a more serious interest in gold market development. If a commitment to marketing their product is made at anywhere near the scale of their commitment to exploration, then the long-term prospects for gold exploration should be good.

In light of these findings, Canadian exploration and mining companies should feel encouraged to make a long-term commitment to gold exploration. Study results indicate that gold exploration in Canada has considerable potential for wealth creation.

However, the time trends analyzed are disturbing. Since 1982, a marked deterioration in the economic performance of gold exploration in Canada is apparent. The search for gold deposits during the 1982-85 interval is found to be a generally marginal economic proposition. Possible reasons for the observed decline in performance have been discussed. In general, gold exploration in Canada during the 1980s has not been as carefully thought out as it formerly was and should be.

Based on gold exploration performance in Canada between 1982 and 1985, a long-term average gold price of almost $600 per ounce (equivalent to US $450 per ounce) will be required to break even on the overall investment made. There is surely a sporting chance that future price levels will be at least this high. We are not confident, however, that this will be so.

To the extent that gold market experts do not think long-term prices will satisfy this minimum acceptable price requirement, and if they are right, some tougher, more general, policy questions arise.

1. What explains the extraordinarily high level of gold exploration which has taken place in recent years?
2. To what extent are short-term corporate forces and government policies promoting uneconomic behaviour?
3. What will be the long-term consequences of this present behaviour?

A final quotation from Adam Smith is in order:

> Mining, it seems, is considered as a lottery, in which the prizes do not compensate the failures, though the greatness of some tempts many adventurers to throw away their fortunes in such unprosperous projects.[19]

Gold exploration is sustainable only if it makes a positive economic contribution to society. Therefore, an important objective should be realization of the full wealth-creating potential of gold exploration for Canada. In this regard, we suggest that the Canadian mining industry and government should prepare to compete efficiently and productively for the worldwide gold mining opportunity by taking appropriate actions to counter the negative exploration trends highlighted.

---

[19] *An Inquiry into the Nature and Causes of the Wealth of Nations*, 1789.

Bibliography

Brook Hunt and Associates, *Western World Gold Mines,* June 1987.

Consolidated Gold Fields, *Gold 1988,* London, May 1988.

Cranstone, D., Mackenzie B., and Doggett, M., "Long-Term Break-Even Price for Canadian Gold Supply", pp. 119-167 in *Long-Term Prospects for Gold Mining*, Proceedings no. 20, B. Mackenzie and R. Gesing, eds., Centre for Resource Studies, Kingston, 1987.

Doggett, M. and Mackenzie B., *Economic Trends in Canadian Gold Supply,* working paper no. 41, Centre for Resource Studies, Kingston, 1987.

Green, T., *The Prospect for Gold: The View to the Year 2000,* Walker, New York, 1987.

Kyle, D.L., "Successful Mineral Discovery - The Statistics, Philosophy and Strategy", pp. 181-198 in *Transactions of the Geological Society of South Africa,* 1984.

Mackenzie, B.W., "Mineral Exploration Economics: Focusing to Encourage Success", pp. 3-21 in *Proceedings of Exploration '87: Third Decennial International Conference on Geophysical and Geochemical Exploration for Minerals and Groundwater,* G.D. Garland ed., Special Volume 3, Ontario Geological Survey, Ministry of Northern Development and Mines, Toronto, 1989.

Mackenzie, B.W. and M.L. Bilodeau, *Economics of Mineral Exploration in Australia: Guidelines for Corporate Planning and Government Policy*, Australian Mineral Foundation, Adelaide, 1984.

Mackenzie, B. and R. Woodall, *Mineral Exploration Economics: The Search for Base Metals in Australia and Canada,* working paper no. 40, Centre for Resource Studies, Kingston, 1987.

McDonald, R.J., *Gold Exploration in Western Australia: The Implications of the Introduction of a Company Tax,* report prepared for Western Australian Gold Mining Policy Committee, Resource Finance Associates, Sydney, April 1986.

McDonald, R.J., "Gold Exploration in Australia: How Long Will the Honeymoon Last?", paper presented at gold exploration symposium, Charters Towers, August 1986.

The Gold Institute, *World Mine Production of Gold 1987-1991,* September 1988.

Woodall, R., "Gold Exploration: Impact of Changing Geoscience Concepts and Technologies", pp. 85-103 in *Long-Term Prospects for Gold Mining.*

The Authors

Brian Mackenzie is a senior research associate of the Centre for Resource Studies and a professor in the Department of Geological Sciences at Queen's University. He received his formal education in mining engineering and mineral economics at McGill University, the University of the Witwatersrand, and Columbia University. In his early years, he worked for Sheep Creek Mines, Union Corporation, the South African Department of Mines, and Energy, Mines and Resources Canada. From 1968 to 1977 he was responsible for teaching and research in mineral economics at McGill University. He was also director of McGill's mining program from 1974 until he joined Queen's University in 1978. Dr. Mackenzie has carried out a wide range of assignments on mineral policy and planning issues for mining companies, governments, and international agencies. In 1977 he was named distinguished lecturer in mineral economics by the Canadian Institute of Mining and Metallurgy, and in 1983 he received the Institute's "Robert Elver Mineral Economics Award". He has presented mineral economics seminars in Canada, Australia, Brazil, Chile, China, Finland, Greece, Indonesia, South Africa, Sweden, Tanzania, and the United States.

Michael Doggett is a research associate of the Centre for Resource Studies at Queen's University. He holds a B.Sc. (honours) in geology from Mount Allison University and an M.Sc. in mineral economics from Queen's University where he is currently enrolled in a Ph.D. program. His background includes mineral exploration in Canada and Australia as well as extensive research into the economics of gold mining in Canada. Present interests and research focus on the costs and benefits associated with the global emphasis on exploration and development of gold deposits.

The Centre for Resource Studies

The Centre for Resource Studies (CRS) was established in 1973, under the sponsorship of Queen's University, the federal Department of Energy, Mines and Resources, and The Mining Association of Canada, to carry out a program of research and publication on mineral policy issues.

The Centre provides opportunities for multidisciplinary research in resource studies at Canadian universities, furnishes reliable information on matters related to mineral resource policy, and promotes closer liaison between government, industry and other concerned groups. The research program is carried out both at the Centre and by means of contracts with qualified investigators, usually at Canadian universities. Small exploratory studies are also funded, through a system of grants-in-aid of research. CRS Policy Discussion Seminars involve representatives from governments, industry, universities, labour, and other interested groups in working sessions on issues of current concern. Through this program of research and seminars, and the resulting publications, the Centre contributes to informed discussions and a better understanding of significant issues.

The Centre is governed by a Board of Directors which establishes general policy and priorities for research. The chairman is Dr. C.G. Miller and the executive director is Mrs. Margot Wojciechowski. There are fourteen other members - seven nominated by Queen's University, four by The Mining Association of Canada, and three by the federal government. Guidance on the research program, together with discussion of policy issues and other matters, is provided by the Advisory Council. This body comprises all researchers associated with the Centre, together with members appointed from such groups as governments, industry, labour, and other interests. A Research Advisory Committee aids in the development of projects and the selection of research proposals. The executive director and staff are responsible for the work of the Centre within this framework.

Most of the funding for the Centre's activities is provided by the sponsors. In addition, the Centre accepts contracts from other organizations interested in mineral policy research.

List of Publications

Monographs

M 24 **Federal and Provincial Taxation of the Canadian Mining Industry: Impact and Implications for Reform**, by R.W. Boadway, K.J. McKenzie, and J.M. Mintz, 207 pp, 1989

M 23 **Metals Demand and the Canadian Metal Industry: Structural Changes and Policy Implications**, by C. Nappi, 145 pp, 1989

M 22 **Pricing of Metals**, by M.E. Slade, 149 pp, 1988

M 21 **Mining Potential in Northern and Southern Canada: Guidelines for Regional Development Policy**, by L.J. Verleun, and B.W. Mackenzie, 225 pp, 1988

M 20 **Canada and International Mineral Markets: Dependence, Instability, and Foreign Policy**, by M. Webb and M. Zacher, 194 pp, 1988

M 19 **The Korean Mineral Market: Opportunities and Marketing Strategies for Canada**, by O.Y. Kwon, 177 pp, 1987

M 18 **An Analysis of Japanese Coking Coal Procurement Policies: The Canadian and Australian Experience**, by D.L. Anderson, 221 pp, 1987

M 17 **Canadian Mineral Policy Past and Present: The Ambiguous Legacy**, by D. Yudelman, 192 pp, 1985

M 16 **National Resources and International Bargaining Power: Canada's Mineral Policy Options**, by P.J. Caragata; 190 pp, 1984

M 15 **Financing Canadian Mining in the Eighties: Strategies for Action**, edited by D. Yudelman; 240 pp, with papers by B. Bradley, A. Dorland, J. Erola, P. Gillin, S. Greenwald, B. Kalymon, P. MacCulloch, B. Mackenzie, K. Murphy, A. Powis, R. Sultan, and D. Yudelman, 1984

M 14 **Foreign Investment Control in the Canadian Mineral Sector: Lessons from the Australian Experience**, by D.L. Anderson; 180 pp, 1983

M 13 **Profitability in the Canadian Mineral Industry**, by C.H. Pye; 178 pp, 1981

M 12 **The Role of Mineral Taxation in Industry/Government Conflict: The Case of the Saskatchewan Potash Reserve Tax**, by D.L. Anderson; 135 pp, 1981

M 11 **The Impact of Policy Change on Decisions in the Mineral Industry: The Case of Exploration in Manitoba, 1969-77**, by B.E. Owen and W.J. Kops; 116 pp, 1980

M 10 **Gold: The World Industry and Canadian Corporate Strategy**, by E. Cousineau and P.R. Richardson; 192 pp, 1980

M 9 **Effects of Taxation on Base Metal Mining in Canada**, by B.W. Mackenzie and M.L. Bilodeau; 188 pp, 1979

M 8 **Environmental Impact of Mining in Canada**, by E.A. Ripley, et al; 274 pp, 1978

M 7 **Economic Impacts and Linkages of the Canadian Mining Industry**, by P.E. Nickel, et al; 140 pp, 1978

M 6 **The Canadian Nonferrous Metals Industry: An Industrial Organization Study**, by E. Urquhart; 158 pp, 1978

M 5 **Health and Safety in the Canadian Mining Industry**, by G.W. Gibbs and P. Pintus; 248 pp, 1978

M 4 **Human Resources in Canadian Mining: A Preliminary Analysis**, by J.A. MacMillan, G.S. Gislason, and S. Lyon; 174 pp, 1977

M 3 **The Transportation Impact of the Canadian Mining Industry**, by A.I. Wallace; 154 pp, 1977

M 2 **The Impact of the Mining Industries on the Canadian Economy**, by R.W. Boadway and J.M. Treddenick; 116 pp, 1977

M 1 **Conflict and its Resolution in the Administration of Mineral Resources in Canada**, by R.M. Burns; 62 pp, 1976

EAS 9 **A Climate for Change: Alternatives for the Central and Eastern Arctic**, by K.A. Graham, M.P.S. Brown, A.B. McAllister, and M.J. Wojciechowski. Final Report of the Eastern Arctic Study, 198 pp, 1984

Proceedings

P 22 **Marketing of Nonferrous Metals**, edited by L.M. Jackson and P.R. Richardson, with papers by R.J. Bauer, L. Spiess, J.E. Tilton, M.E. Slade, C. Green, R. Bhar, W.H. Dresher, W. Deeks, L.A. Morris, H. Wynne-Edwards, and L.M. Jackson, 131 pp, 1989

P 21 **Prospects for Minerals in the 90s**, edited by P.R. Richardson and R. Gesing, with papers by P.R. Richardson, N. Keevil Jr., J. Macleod, J. Cordes , S. Hunt, J. Zwartendyk, P. Perron, P. McGeer, B. Harris and A. Cecutti, and R. Gesing and M.J. Wojciechowski, 149 pp, 1988

P 20 **Long-Term Prospects for Gold Mining**, edited by B.W. Mackenzie and R. Gesing, with papers by J. Nichols, T. Green, J. Fisher, M. Murenbeeld, G. Anders, R. Woodall, D. Krige, D. Cranstone, B. Mackenzie, M. Doggett, B. Kalymon, C. Margueron, M.J. Wojciechowski, and W.K. Buck, 233 pp, 1987

P 19 **Technology Policies in the Canadian Mineral Industry**, edited by M.J. Wojciechowski, with papers by R. Woodbridge, M.J. Wojciechowski, F. Pickard, D. Bevelander, J. Hood, W.G. Jeffery and J. Kuryllowicz, P. Richardson, J. Schade, W. Curlook, and G. Miller, M. Sayer, G. Hatch, D. Hutchinson, and A. Molinari, 179 pp, 1986

P 18 **Structural Changes in the World Mineral Industry: Implications for Canada**, edited by M.J. Wojciechowski, with papers by P. Crowson, S. Hunt, G. Haclin, J. Davies, D. Karvonen, G. Denis, D. Daly, D. Haglund, I. Bennett, G. Mahoney, K. Buck, 213 pp, 1986

P 17 **Canadian Mining Taxation**, edited by M.J. Wojciechowski, with papers by G. Langlois, D. Williams, T. Enemark, P. Halkett, R. Albert, K. Service, K. O'Brien, R. Boadway, J. Mintz; 144 pp, 1985

P 16 **Mining Productivity**, edited by M.J. Wojciechowski, with papers by P.R. Richardson, K. Stollery, H. Martin, B.W. Mackenzie, C.G. Miller, W. James, P. Lepage, K. Whitham, W. Curlook, and E. Kossatz; 187 pp, 1985

P 15 **Native Participation in Mineral Development Activities**, edited by M.J. Wojciechowski, with papers by A. Clark and M. Lalonde, K.A. Graham, B.W. Mackenzie, C.D. Hunt, J-L Blais, F.R. Joubin, E. Laliberte; 150 pp, 1984

P 13 **Mineral Policy Formulation: The Role of Scientific and Technical Knowledge**, with papers by B. Mackenzie, G.A. Jewett, H.D. Dreschler, P.G. Halkett, D.E. Bond, D.C. Findlay, W.G. Jeffery, L.G. Bonar, D.W. Davis, J. Zwartendyk; 135 pp, 1982

P 12 **Acid Rain Controls and the Economics of the Canadian Nonferrous Mineral Industry**, with papers by J. Gerin, W.G. Deeks, P.R. Clarke, J.B. Hyne, H.T. Fargey, B.W. Mackenzie, and E.J. Ward; 90 pp, 1982

P 11 **Skilled Manpower Shortages in the 1980s: Towards a Cooperative Solution**, with papers by R.J. Gray, J.S. Reid, W.H. Digby, J.R. Hopkinson, A. Knoll, O. Tremblay, G. Betcherman, P.E. Womersley, M.J. Alton, V.C. Allman, C. Stairs, E.J. Weiss, and W.E. McBride; 116 pp, 181

P 10 **Northern Mining in the 80s**, with papers by G. Braden, R.J. Cathro, D. MacKinnon, J. Smith, R.W. Stephenson, B.E. Novak,E.N. Doyle, J.R. Witty, J.E. Marshall, A.G. Gordon, J. McCormack, H.B. Hicks, J. Zigarlick, T. Shearcroft, W. Kupsch, J. Stabler, J. Erola; 110 pp, 1980

P 8 **Mining-Linked Diversification of the Sudbury Basin Economy**, with papers by D.C. Frith, J.P. Remy, A.I. Wallace, J.H. Holtby and L.C. Kitchener; 53 pp, 1980

P 7 **The Future for Junior Mining in Canada**, with papers by Hon. J.A.C. Auld, J.L.C. Lyndon, N.B. Keevil Jr., D.G.C. Menzel, H.T. Fargey, A.J. Freyman, John. R. Hnatyshyn, J.C. Baillie, D.W. Scrim, J.P. Bunting, E.H. Neave and P.R. Richardson, L.A. English, M. St.-B. Harrison,

P 5 **Employee Relations Initiatives in Canadian Mining**, with papers by W.J. Bennett, F.R. Nogas and J.P. Fulcher, W.F. Clarke, S.B. Jones, T.F. Cawsey and P.R. Richardson, and P. Warrian; 85 pp, 1979

P 4 **Canada's Mineral Trade: Implications for the Balance of Payments and Economic Development**, with papers by B.W. Wilkinson, D.J. McCulla, J.G. MacKinnon, A.G. Balogh, W.G. Chambers and J.S. Reid; 113 pp, 1978

P 3 **Current Concerns in Mineral Policy**, with papers by C.R. Archibald, W.J. Barbour, D.B. Brooks, J.S. Dowsett, J.M. Fleming, and G.A. Jewett; 75 pp, 1978

P 2 **International Competition and the Canadian Mineral Industries**, with papers by H.C. Armstrong, H.T. Fargey, C.G. Miller, N.D. Olewiler and P.R. Richardson, D. Peristein, and K.C. Hendrick; 109 pp, 1978

Working Papers

WP 44 **Economic Aspects of Gold Exploration: How Much Is Too Much**, B.W. Mackenzie and M. Doggett; 30 pp, 1989

WP 43 **Long Distance Labour Commuting in the Canadian Mining Industry**, by K. Storey and M. Shrimpton; 45 pp, 1989

WP 42 **The Changing Transportation Environment of the Canadian Mineral Industry**, by I. Wallace; 37 pp, 1987

WP 41 **Economic Trends in Canadian Gold Supply**, by B.W. Mackenzie and M. Doggett; 80 pp, 1987

WP 40 **Mineral Exploration Economics: The Search for Base Metals in Australia and Canada**, by B.W. Mackenzie and R. Woodall; 112 pp, 1987

WP 39 **Flow-Through Share Financing**, by B. Kalymon; 63 pp, 1987

WP 38 **Value Added Taxation: Issues and Impact for Canadian Mines**, by B.J. Dyack; 62 pp, 1986

WP 37 **Intergovernmental Mineral Commodity Arrangements**, by W.K. Buck; 70 pp, 1986

WP 36 **Mine Infrastructure and Economic Development in North Australia**, by C. O'Faircheallaigh, 104 pp, 1986

WP 35 **Effects of Location on the Competitive Position of Mineral Exploration and Development Opportunities in Canada**, by B.W. Mackenzie, D.W. Davis and M.L. Bilodeau; 72 pp, 1986

WP 34 **Mining and the Macdonald Commission: The State of the Industry in the Mid-1980s**, by D. Yudelman, 116 pp, 1985

WP 33 **The Origins of Public Enterprise in the Mineral Sector: Three Provincial Case Studies**, by M.J. Prince and G.B. Doern, 143 pp, 1985

WP 32 **Productivity and Price: The Case of Gold in Ontario**, by A.G. Green, 54 pp, 1984

WP 31 **Federal Policy and the Role of the Public Enterprise in the Mining Sector**, by M.J. Prince and G.B Doern, 52 pp, 1984

WP 30 **Canadian Mineral Policy Formulation: A Case Study of the Adversarial Process**, by D. Yudelman, 83 pp, 1984

WP 28 **Economic Mineral Exploration Targets**, by B.W. Mackenzie; 72 pp, 1984

WP 25 **Economic Guidelines for Small Mineral Deposit/-Directives economiques relatives aux petits gisements**, by B.W. Mackenzie and M.L. Bilodeau; 66 pp, 1982

WP 24 **The Costs of Uncertainty: Regulating Health and Safety in the Canadian Uranium Industry**, by I. Robinson; 74 pp, 1982

WP 23 **Effects of Water Pollution Control Costs on Base Metal Mining in Canada**, by N.A. Papanicolaou and B.W. Mackenzie, 74 pp, 1981

WP 22 **Newfoundland Mining Industry: Present Status and Potential for Expansion**, by N.D. Olewiler and C.H. Pye; 208 pp, 1980

WP 21 **Public Affairs and the Minerals Industry: Junior Mining; Northern Development; Loans for Foreign Mines; A Public Relations Strategy**, by C.G. Miller, 42 pp, 1980

WP 20 **The Market Price of Risk in the Canadian Mining Industry**, by H.F. Campbell, 29 pp, 1980

WP 18 **An Economic Analysis of the Canadian Taxation of an Integrated Mining Company**, by J.-T. Bernard; 112 pp, 1980

WP 17 **Constitutional Change and the Mineral Industry in Canada**, by W. MacDonald; 66 pp, 1979

WP 16 **Canada's Competitive Position in Copper and Zinc Markets**, by B.W. Mackenzie; 41 pp, 1979

WP 15 **Public Policy Aspects of Information Exchange in Canadian Mineral Exploration**, by D.O. Downing and B.W. Mackenzie; 52 pp, 1979

WP 13 Cerro Colorado: A Case Study of the Role of Canadian Crown Corporations in Foreign Mineral Development, by C.G. Miller, N.D. Olewiler, and P.R. Richardson; 44 pp, 1979

WP 10 Canada as a World Zinc Producer: Prospects to 1980, by N.D. Olewiler, P.R. Richardson, and L. Rumble; 72 pp, 1978

WP 9 Trends in Canada's Mineral Trade, by B.W. Wilkinson; 63 pp, 1978

WP 8 Federal Mineral Policies: 1945-75, by M.J. Wojciechowski; 85 pp, 1979

Technical Papers

T 10 Economic Potential of Base Metal and Gold Mining in Newfoundland: Assessing the Impact of Regional Development Policy Options, by B.W. Mackenzie, M.L. Bilodeau, and M. Doggett; 201 pp, 1989

T 9 Mineral Exploration and Mine Development Potential in Ontario: Economic Guidelines for Government Policy, by B.W. Mackenzie, M.L. Bilodeau, M. Doggett; 209 pp, 1989

T 8 An Inter-Sectoral Study of Canada's Resource Industries, by T. Bennett and D.L. Anderson; 197 pp, 1988

T 7 Innovation in the Mineral Industry: Opportunities and Strategies for Canada, by M.J. Wojciechowski and P.R. Richardson, 278 pp, 1987

T 6 Geological Aspects of Mining Productivity, by B.W. Mackenzie, 115 pp, 1985

T 4 Mineral Technology Transfer: Evaluation of the CANMET Fit Slope Project, by B.W. Mackenzie and R. Pakalnis, 200 pp, 1985

T 3 Secondary Supply of Copper and Ferrous Metals and Canadian Metal Markets, by K.R. Stollery, 118 pp, 1983

T 2 Economic Effects of Smelter Controls on the Canadian Nonferrous Mining Industry, by B.W. Mackenzie and M. Bilodeau; 162 pp, 1982

Mineral Policy Updates

MP 84 Mineral Policy Update: 1984, by M.J. Wojciechowski; 118 pp, 1985

MP 83 Mineral Policy Update: 1983, by M.J. Wojciechowski; 88 pp, 1984

MP 82 Mineral Policy Update: 1982, by M.J. Wojciechowski and C.E. McMurray; 88 pp, 1983

MP 81 Mineral Policy Update: 1981, by M.J. Wojciechowski and C.E. McMurray; 85 pp, 1983